RESEARCH DEPARTMENT

CORRELATION TECHNIQUES IN STUDIO TESTING

Research Report No. B-082

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(Based on a paper appearing in the Journal of the Brit.I.R.E.)

SUMMARY

Correlation techniques allow the separation of signals which have arrived by paths of different transit times or have originated from different sources. This ability is of assistance in certain types of acoustic testing in studios or other enclosures.

The construction of an analogue correlator to derive the correlation function between two signals is described. Its application both in laboratory and in field measurements has confirmed and supplemented results obtained by other techniques. Sound reduction measurements and the identification of flanking paths have proved to be the area in which the technique has the greatest value. Details of laboratory and field measurements are reported.

1. INTRODUCTION

In many respects broadcasting studios represent the most stringent requirements in acoustical design. It is necessary to provide a suitable acoustical environment to stimulate the people involved and it is further necessary that the programme shall be clearly intelligible to the listeners. Except in stereophonic broadcasting a single chain exists between the programme source and the listener, who is thus prevented from using his binaural faculties to differentiate between wanted and unwanted sounds; for example, no separation can be obtained between a speaker's voice and extraneous noises or excessive reverberation.

The points which are implicit in these requirements will not be discussed here, but they necessitate a close control over the reverberation times at all frequencies, the provision of acoustic isolation between neighbouring areas, the reduction of noise arising within the studios and similar measures.

Many techniques have been developed to provide such information and a notable addition to the range of equipment was made in 1955 when K.W. Goff[1,2] described the construction and application to acoustics of an analogue electronic correlator. A correlator of basically the same type has been constructed in the Acoustics Section of Research Department and has been used from time to time in the intervening years. Some of the experimental results obtained will be used to illustrate the application and limitations of the equipment.

The theory of correlation is a familiar tool of the statistician who uses it to express the degree of dependence of one set of variables upon a second set. In time series the correlation which chiefly comes into play is that between a certain sequence of values and the same or another sequence of values after a shift in time. Where we are dealing with continuous data* we consider the time function $f(t)$ and we define the cross correlation function $\phi_{21}(\tau)$ between two such times series, $f_1(t)$ and $f_2(t)$, with a time delay τ applied to one as:

$$\phi_{21}(\tau) = \lim_{T \to \infty} \frac{1}{T}\int_0^T f_1(t).f_2(t - \tau)\, dt \qquad (1)$$

If the correlation function has a maximum at some delay τ_1, then it will be found to have a finite value for a range of delay times around τ_1. The range of delay times is inversely proportional to the bandwidth common to both input signals. Thus, provided the integrating time of the equipment is large compared with this time interval, the error introduced by a finite time integration will be small. The correlation function is taken as

$$\phi_{21}(\tau) = \frac{1}{T}\int_0^T f_1(t) \quad f_2(t - \tau)\, dt \qquad \text{for } T \gg \frac{1}{\Delta\omega} \qquad (2)$$

where $\Delta\omega$ is the bandwidth common to both $f_1(t)$ and $f_2(t)$.

The correlator shown in block schematic form in Fig. 1 performs the operations defined in (2) directly on the input signals.

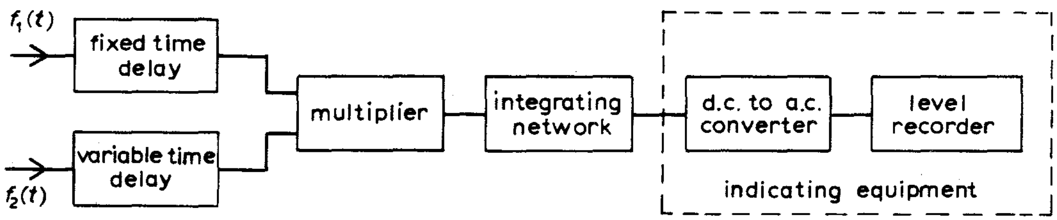

Fig. 1 - Block schematic of correlator

A simple low pass filter of suitable time constant carries out the integration. The method chosen for the multiplication of the functions is that known as a 'quarter squaring multiplier' which derives the product from the relationship

$$f_1(t).f_2(t - \tau) \equiv \frac{1}{4}\{[f_1(t) + f_2(t - \tau)]^2 - [f_1(t) - f_2(t - \tau)]^2\}$$

The construction of the correlator is described in greater detail in the Appendix, particular attention being paid to the points at which it differs from that described by Goff.

2. THE OPERATION OF THE CORRELATOR

2.1. The Effects of Filtering on the Correlation Function

The autocorrelation function of a pure tone has the same periodicity as the tone and therefore, since there will be a maximum each time the path difference

*Excluding the case of periodic functions

between the signals is a multiple of a wavelength, no unambiguous information on the time delay corresponding to different path lengths can be obtained. On the other hand the autocorrelation function of a random signal of infinite bandwidth has a finite value only at zero relative delay. When the bandwidth of one of the signals applied to the correlator input is limited, the correlation function takes the form of a damped oscillation in which the period of the oscillation is that of the centre frequency of the pass-band, while the overall width of the pattern is a function of the bandwidth of the signal.

Information can now be derived on the behaviour of this band of frequencies but the ability to discriminate between delay times is restricted by the necessity to resolve adjacent groups of peaks. Even when it is possible to see that two groups of peaks exist, the peak heights may be modified by the skirts of the adjacent group. Thus by adjusting the bandwidth a compromise between frequency discrimination and path length information can be achieved.

2.2. Limitations in the Application of the Correlator

There remain two major limitations to the application of the correlator in studio testing. The first is the physical size of the equipment which cannot be readily transported to studio centres around the country. This limitation was overcome in the first instance by the use of the lines which interconnect most studios. Measurements were successfully carried out on one occasion lasting several days in which this method was employed. However, the second limitation is the time involved in these measurements, which remains excessive since it can take at least thirty minutes to correlate over a time delay corresponding to a path length of forty feet ($\sim$12 m) at a rate suitable for a high signal to noise ratio. Studios are not normally available for such periods of time as would be required for measurements in several frequency ranges, and we have therefore had to rely on recordings of test signals which could be brought back to the laboratory for analysis. A twin-track tape recorder enables the phase relationship between the two channels of information to be maintained to an adequate degree. It is not necessary to have a continuous recording of the noise, a loop of duration greater than the integrating time of the correlator being sufficient; this is replayed continuously to the analysis equipment.

Since most high quality loudspeakers contain crossover networks which will introduce unknown phase shifts at mid-frequencies, it has become general practice to use such a speaker for the lower frequency measurements only and a horn loaded pressure unit for the high frequencies. Recordings are therefore made with each loudspeaker and the necessary microphone positions.

3. APPLICATION OF THE CORRELATOR TO SOUND REDUCTION MEASUREMENTS

3.1. General

The sound transmission coefficient of a partition is defined as the ratio of the sound energy transmitted through the partition to the energy incident on it, and the sound reduction factor is

$$10 \log_{10} \left(\frac{1}{\text{sound transmission coefficient}} \right)$$

For the simple case of a free travelling sound wave the sound reduction factor is 20 $\log_{10}$ (Pi/Pt) where Pi is the incident sound pressure and Pt the transmitted sound pressure.

In the case of a single mass-controlled limp partition, the sound reduction factor can be approximated at normal incidence by the expression 20 $\log_{10}$ $(\omega M/2\rho_0 c)$ where ω is 2π times the frequency, M is the area density of the partition and $\rho_0 c$ the characteristic impedance of air. For a given material this expression will be seen to increase by 6 dB for each doubling of the frequency or, for a given frequency, to increase by 6 dB for each doubling of the mass.

The use of a correlator enables a determination of the incident and transmitted sound pressures to be made under conditions where conventional measurements are impossible or at least could give misleading answers. The ability to differentiate between sound which has arrived by paths of different lengths enables measurements to be carried out on samples of limited size since the energy which has been transmitted through the sample can be separated from that which has come round the edges.

An alternative method has been proposed by Professor Raes[3] in which a short pulse is radiated and picked up by microphones on each side of the partition. The signals, suitably amplified, are exhibited on an oscilloscope and the amplitude of the pulses arriving with different transit times measured from photographs of the traces. This method is equivalent to correlation and for a given bandwidth of signal has the same ability to separate paths of different lengths in the absence of extraneous noise. The signal to noise ratio obtainable in correlation is, however, considerably better than with the short pulse method.

A loudspeaker driven from a random noise generator is used as the correlation source, and Fig. 2 shows two possible ways of operating the equipment. The

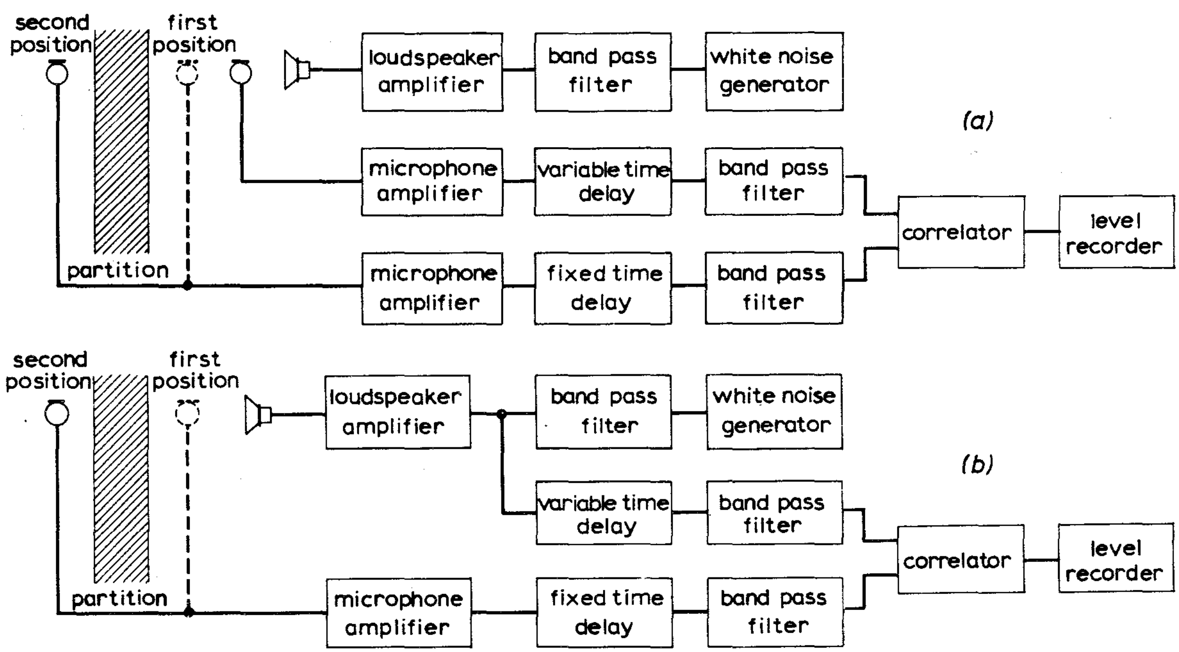

Fig. 2 - Block schematic of correlator measurements

(a) Correlation of two microphone outputs
(b) Correlation of loudspeaker input and microphone output

first uses two microphones, the electrical outputs of which, after suitable amplification, are applied to the correlator. As the time delay is varied a maximum of the correlation function will be obtained for each delay corresponding to a path traversed by sound between the two microphones. An improved method in which the output of a single microphone is correlated against the electrical input to the loudspeaker has considerable advantages in protecting against spurious reflections within the source room and, of course, simplifies the equipment necessary.

3.2. Measurements on a Small Panel

The sound reduction factor of a limp panel of lead loaded P.V.C. was determined both by the correlator and by conventional measurements. The sample was of limited size (6 ft 6 in × 2 ft 9 in, or 1·98 m × 0·84 m), and correlator results could be obtained only for normal incidence where the line joining loudspeaker and microphone is normal to the panel.

A microphone was placed approximately 30 in (76 cm) from a horn loaded pressure unit and a series of correlator traces made in different octave bands. The test panel was then placed between the loudspeaker and the microphone and the procedure repeated. After allowing for changes of microphone amplifier gain, the change in height of the correlation peak, which arrived after the same time delay as found previously, represented the change of sound pressure level at that point.

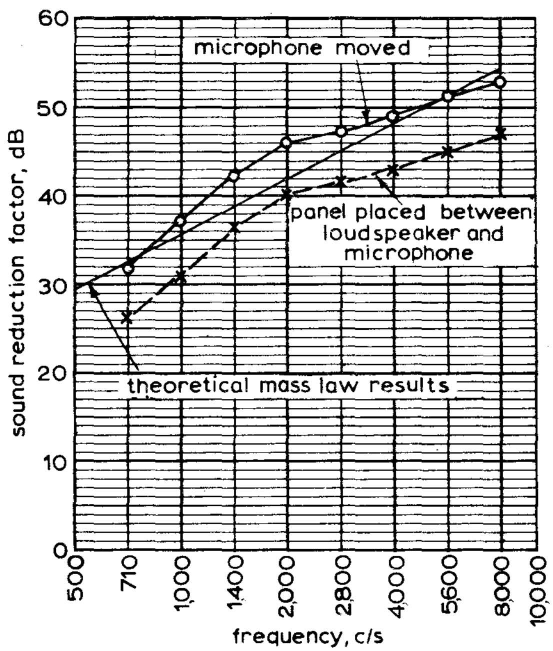

Fig. 3 - Sound reduction index of lead loaded P.V.C. membrane by correlator measurement

In fact the material proved to have too high a sound reduction factor for straightforward measurements, the reverberant energy making recognition of the direct peak impossible. The panel was fitted loosely into a doorway to reduce the reverberant energy and the results obtained are shown in Fig. 3 (lower curve). For comparison purposes the theoretical mass law values are shown on the same graph.

In Fig. 4, measurements made by the conventional method are compared with the same theoretical value. In this case the door-shaped panel had to be securely fastened in a door opening. A diffuse sound field existed on the source side of the panel and theory would indicate that for random incidence on a mass-controlled panel the results would lie 6 - 10 dB below the normal incidence case. In the region from 350 c/s to 2 kc/s this result holds fairly well; above 2 kc/s the reduction of the measured values below those expected could be due to the difficulties of providing adequate seals around the edges of the sample.

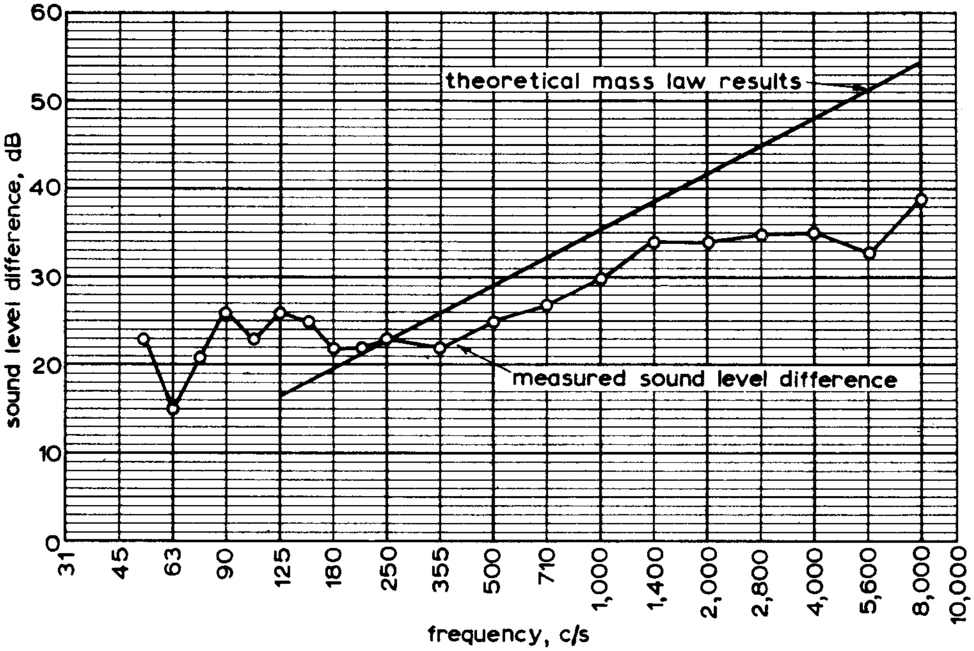

Fig. 4 - Sound level difference given by lead loaded P.V.C. membrane

If the partition which is to be measured is not portable, then a determination of the incident energy has to be made with the microphone placed first on the source side. At low frequencies difficulties will arise in the separation of the direct and reflected sound and it will become necessary to increase the spacing of the microphone from the wall.

In addition, account has to be taken of a factor due to the divergence of the energy from the loudspeaker. In typical cases a difference of 6 - 8 dB in sound pressure might be found between the two microphone positions. The sound pressure incident on the panel will be between the two values found. The measurements on the lead loaded P.V.C. were repeated in this way and the results were found to be greater by the expected amount than those measured previously (see upper curve in Fig. 3).

For octave bandwidths of sound, results can be obtained at and above frequencies for which the wavelength of sound in air is half the minimum dimension of the panel being measured; above this frequency it is possible to separate sound transmitted through the panel from that which has passed round the edges of the sample.

3.3. Measurements on an Experimental Partition

A further experimental application of the correlator was in the determination of the maximum possible sound reduction indices which could be obtained from a complex partition. A fuller description of this work may be found in Reference 4.

A double skin construction of expanded metal lath and plaster suspended by springs from a central framework was erected in an existing enclosure to determine

the sound reduction indices of which it was capable. On completion, the conventional measurements gave poor results and it was subjectively apparent that many flanking paths existed. The correlator was used with broad bands of noise radiated from a loudspeaker and picked up by a microphone which was placed first directly in front of the loudspeaker and subsequently on the distant side of the partition.

High values of the sound reduction index were obtained in these measurements, no directly transmitted energy being apparent on the traces shown in Fig. 5. Minimum

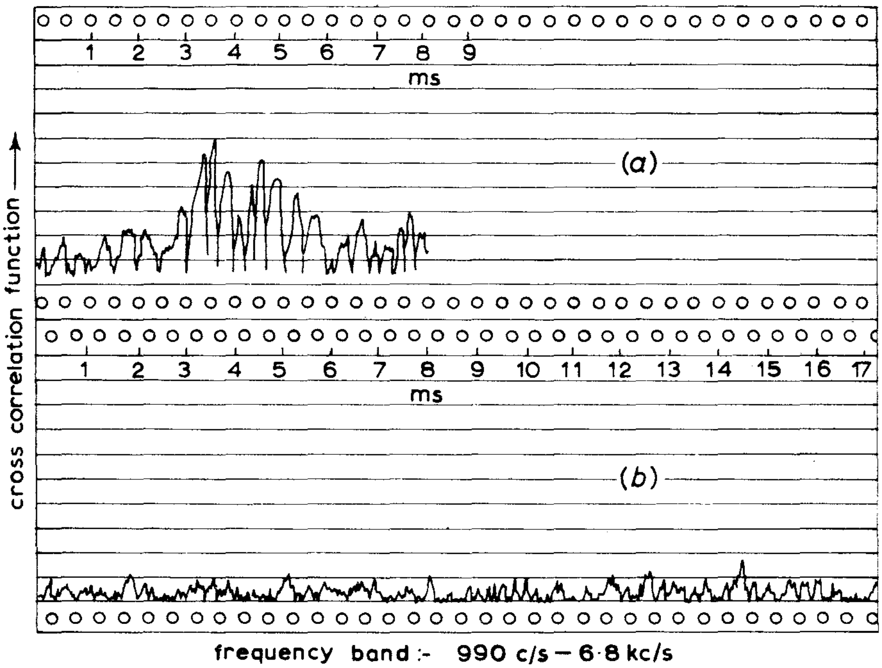

Fig. 5 - Examples of correlator traces

(a) Trace with microphone in front of wall (mic. amp. gain 80-44 dB)
(b) Trace with microphone behind wall (mic. amp. gain 80 dB)

values were deduced for the sound reduction index and are shown in Fig. 6. They indicate that the experimental wall was behaving much as could be expected from a partition of this type. The results obtained by correlation were confirmed in this case by short pulse measurements (Fig. 6).

It is obvious that one shortcoming of both these measurements is that they provide results at normal incidence only. No indication would therefore be given of lower values of the sound reduction index that might exist at other angles of incidence and would tend to reduce the sound reduction index as the term is normally defined and used. Such an effect was postulated by Cremer[5] and is known as the coincidence effect. At a frequency for which the speed of flexural waves in the surface is equal to the speed of progression of the incident wave front along the surface, resonance occurs and a low sound reduction index is found. The lowest frequency at which this occurs, the critical frequency, corresponds to sound at

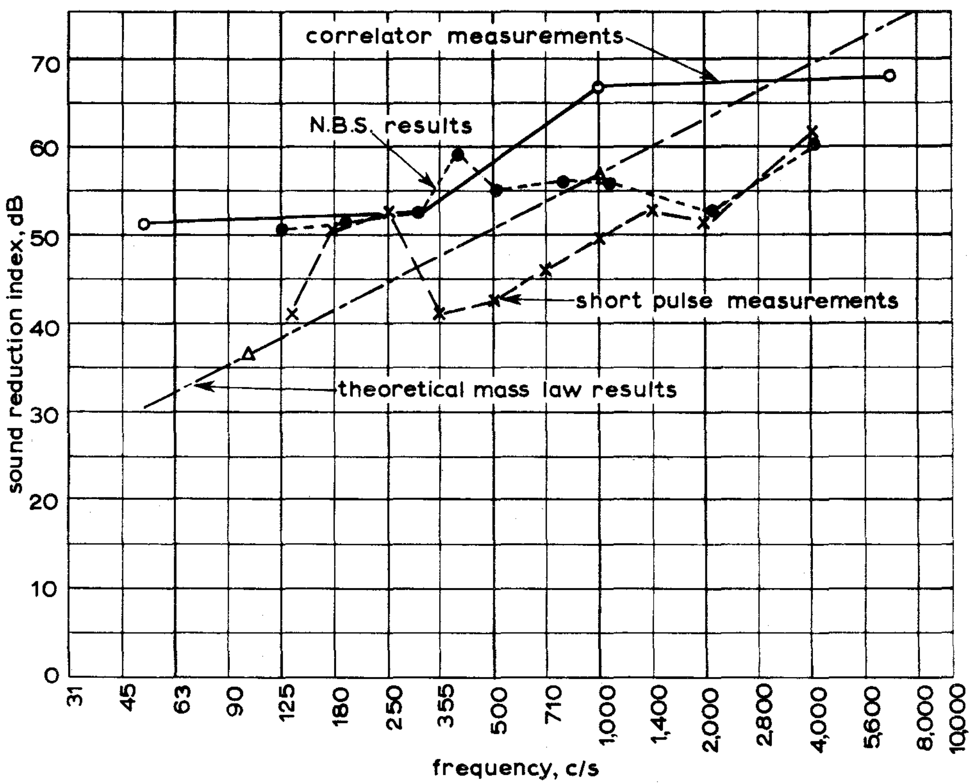

Fig. 6 - Sound reduction indices for partition wall

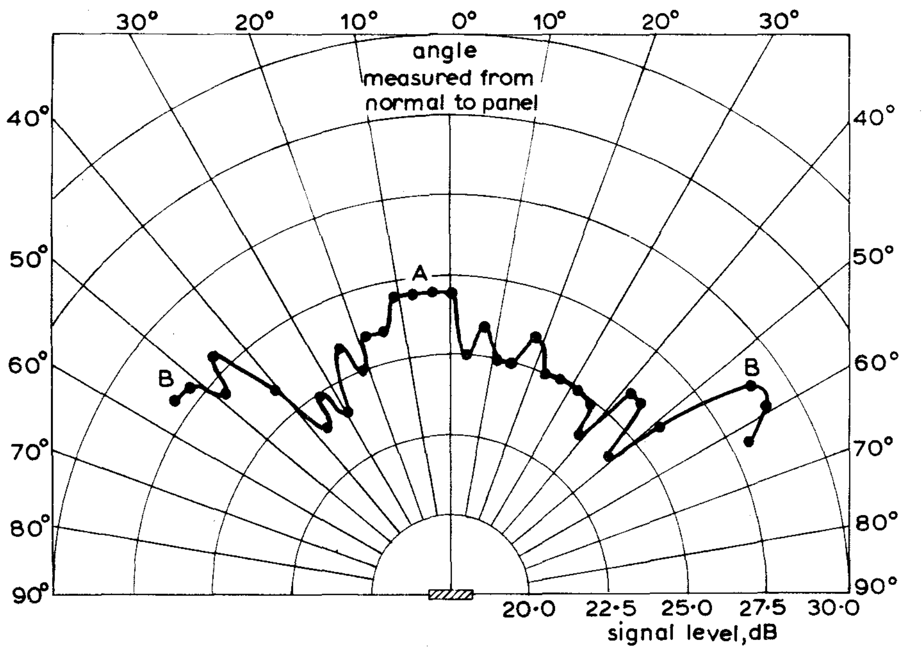

Fig. 7 - Polar diagram of radiation from a 3/16th inch aluminium sheet

grazing incidence exciting the flexural waves; for all higher frequencies there will exist some angle of incidence of the acoustic waves which will satisfy the above condition.

The coincidence effect was demonstrated in the laboratory for a 3/16 in (4·8 mm) sheet of aluminium which was sealed into an opening. A sound field which was approximately diffuse was set up on the source side and the sound pressure level on the other side measured at a reasonable distance to define the angle from which the radiation was received. The results obtained with warble tone of centre frequency 4 kc/s are shown in Fig. 7 where a lobe B is found at an angle of 57°. There is also a lobe A in the forward direction but this is principally due to a higher incident energy in this direction. The measurements were repeated with two other frequencies and from the measured coincidence angles the critical frequency for this thickness of aluminium sheet was calculated. The results are shown in Table I, and may be seen to be reasonably self consistent and to agree with a theoretical value derived from the constants of the material.

Correlation measurements were made with the line joining loudspeaker and microphone at the coincidence angle for an octave band of white noise centred on 5·6 kc/s and showed a sound reduction factor which was 5 dB below that for normal incidence when measured close to the panel and 10 dB lower at the distance used in the previous measurements.

TABLE 1

Critical frequencies calculated from measured coincidence angles for 3/16 in (4·8 mm) aluminium sheet (compare with 2·4 kc/s critical frequency calculated from constants of material)

FREQUENCY	MEASURED COINCIDENCE ANGLE	CRITICAL FREQUENCY
4·0 kc/s	57°	2·83 kc/s
4·8 kc/s	52°	2·88 kc/s
5·6 kc/s	44°	2·75 kc/s

With this confirmation that a correlator could indicate a coincidence frequency, measurements were repeated on the experimental wall using five angles of incidence and four frequency bands. No evidence was obtained for the existence of a coincidence effect.

If a true measure of the sound reduction index of a partition were required, it would be necessary to measure at several angles of incidence and to integrate the energy transmission expected at each angle.

As previously, results for octave bands can be obtained at or above frequencies for which the wavelength of sound is half the minimum dimension of the panel being measured. Additional limitations affect low frequency measurements due to an inability to separate direct and reflected sound.

3.4. Measurements in a Studio

A major factor in the design of a broadcasting studio is the provision of adequate acoustic isolation between the studio, its associated control cubicle and

surrounding areas. Failure to achieve sufficient protection can give rise to 'howl round' between a studio and the cubicle where the programme is being monitored on a loudspeaker, or interfering noise from surrounding areas.

Conventional measurements involve the determination of the sound pressure level on either side of the common wall which frequently contains doors, windows, ventilation trunking and other possible weak links. When values of sound level reduction are found to be lower than those expected from the type of construction some indication may be given by this form of measurement as to where the leakage is occurring, but generally the reverberant energy is sufficient to make this impossible. Correlation will enable us to determine the energy associated with the sound arriving by different routes with different delays and it may prove possible to associate particular time delays with certain of the physical features of the construction. If measurements are carried out with at least two sets of microphone positions, the additional information often permits the recognition of a flanking path with a fair degree of confidence.

Measurements of this kind were carried out in an enclosure converted to a film dubbing suite by mounting a partition containing a double door and double glazed window across the centre. When the suite was tested after construction a low frequency oscillation or 'howl round' was found to build up between the microphone in the studio on one side of the partition and the loudspeaker at the other side which was used as a control cubicle. Conventional sound reduction measurements showed low values at low frequencies but, of course, gave little idea of the position of the leakage. Recordings for correlation analysis were made at both sides of the room and with high and low microphone positions on the transmitted side. The results which are shown in Fig. 8 compare conventional measurements with that set of

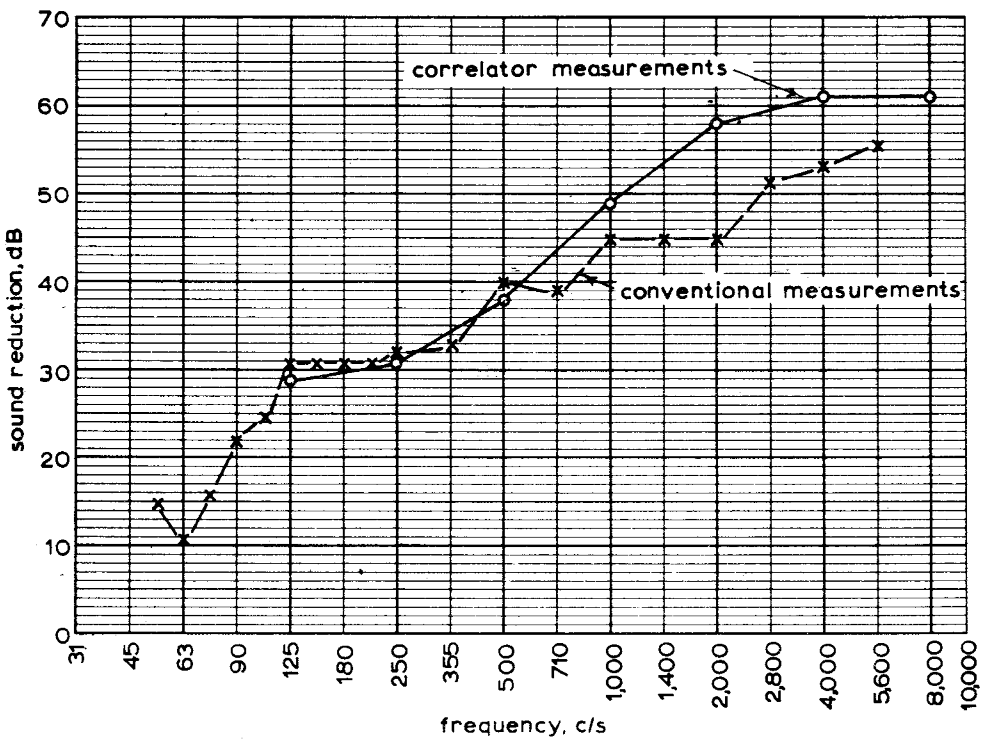

Fig. 8 - Level difference produced by a partition

correlator results showing the earliest arrival of the largest amount of energy. The agreement at lower frequencies has proved better than would be expected but the principal achievement of the technique was shown in the difference between sets of traces. Those obtained when the loudspeaker and microphone were at the right-hand side of the cubicle showed a flanking path long compared with the direct transmission. When the loudspeaker and microphone were transferred to the left-hand side, the main path became the shortest path.

Examination of the suspect corner subsequently showed that the leaves of the partition had not been carried solidly on to the structural walls of the building. There existed a path of low insulation passing through the acoustic treatment and around the edge of the partition.

In the search for flanking paths, it is often found that the most direct distances involved do not correspond to the measured time delays. This may be due to the directionality of the loudspeakers, where the energy emitted at right angles to the axis is normally considerably less than that along the axis. Thus a wave which has been reflected across the room and through an opening may still contain more energy than one travelling directly to the opening.

4. APPLICATION OF THE CORRELATOR TO ABSORPTION MEASUREMENTS

4.1. General

In studios it is considered essential that the reverberation time of the enclosure should be adjusted to a value which is determined by its use and volume and that the reverberation time-frequency characteristic shall be flat at this value. To meet these requirements, suitable absorptive treatment is mounted on the surface of the room. It frequently occurs that when acceptance tests are made the reverberation time does not achieve its designed value over part or the whole of the frequency range. It would be of great assistance in the correction of such faults if they could be attributed definitely to particular absorbers. Attempts have therefore been made to determine the reflection coefficient of a surface in situ using a correlator.

The accuracy obtainable in these measurements is limited, but provided care is taken to control such factors as can be controlled, an indication of the reflection coefficient and hence the absorption of the surface can be obtained.

Level stability of the white noise generator is difficult to ensure due, apparently, to minor variations in the emission from the cathode of the thyratron used in the equipment for generating the white noise. A magnet attached to one side of the valve to reduce fluctuations in the electron beam has eliminated most of the major changes but there remain short-term fluctuations of the order of ½ dB. Since this variation occurs in both signals, a change of 1 dB in the correlated output is possible. This corresponds to a change of 10% in the measured reflection coefficient and hence to an uncertainty of 20% in the corresponding absorption coefficient.

In all practical cases it would be necessary to determine for a particular loudspeaker the fall of pressure with distance and it seemed simplest to reduce the experiment to a comparison of the reflection coefficient of the absorbing surface with that of a reflecting surface. The loudspeaker and microphone were set on the normal to the surface and a sufficient distance from it to enable the direct and reflected peaks of the correlation function to be separated. A sheet of plate glass held against a wall was taken to be a perfect reflector at the frequencies at which these measurements were possible.

An increase in the ratio of direct to reflected sound when the absorber is substituted for the plate glass is due to absorption at the surface. The reflection coefficient is therefore calculable and the absorption coefficient, being $(1 - r^2)$ where r is the pressure reflection coefficient, can be calculated.

An octave band centred on 1 kc/s was found to contain the lowest frequencies at which measurements could be made. The microphone-wall spacing was increased to 2 ft (61 cm) and in order to maintain a reasonably low direct to reflected signal ratio, the loudspeaker to microphone spacing had to be increased to 3 ft (91 cm). Spurious reflections from ceiling or walls prevented a lower frequency from being employed.

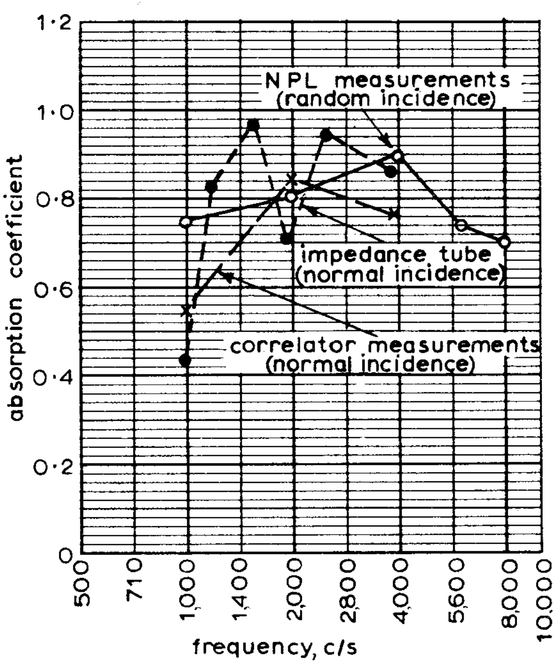

Fig. 9 - Absorption coefficients of an acoustic tile

4.2. Measurements on a Proprietary Absorber

In a recent case a studio showed a rise of reverberation time at high frequencies, the subjective effect of which was accentuated by a fall at 250 - 350 c/s. Doubt was case on the behaviour of the ceiling tiles which, together with a carpet, comprised practically all the high frequency absorption. Reflection coefficient measurements were made at normal incidence using the correlator, a sample of the tiles being mounted against the wall of a large room and a loudspeaker and microphone placed in line in front of it.

The results are shown in Fig. 9 together with the reported absorption coefficients obtained by the National Physical Laboratory. The N.P.L. results are random incidence coefficients determined under standard conditions in a reverberation room and so are not strictly comparable. The other results shown for comparison were obtained by mounting the tile against the end of an impedance tube and determining the pressure distribution in a standing wave set up between a loudspeaker and the tile. The results are strictly comparable with those obtained by the correlator, being obtained at normal incidence. The greater frequency range in which the measurements could be made enabled a verification of the fact that the unexpectedly high absorption in the 250 - 350 c/s region was produced by the tiles in combination with the deep air space above a false ceiling construction.

The correlator gave reasonable results which could be obtained without demounting the absorber. However, the restricted frequency range must limit very severely the applications of the technique.

5. APPLICATION OF THE CORRELATOR TO MEASUREMENTS IN A VENTILATING SYSTEM

On occasion the need has arisen to determine the noise developed by a ventilating fan or to determine the reduction of this noise produced by silencing elements within the ventilation system. This implies measurement made in the moving air stream of the fan noise in one case and possibly of an external noise source in the other. In view of the high air speeds employed in high velocity ventilation systems (say 3000 feet per minute), a streamlined probe microphone was constructed to carry out measurements in such a system but failed because of the noise generated by the air stream.

The correlator provides a possible means of measuring such noise if two microphones are placed side by side in the air stream. The noise generated by the wind at each microphone should be incoherent and the correlated output should be obtained only for noise generated up or downstream of the measuring point.

6. CONCLUSIONS

Correlation techniques provide a means of analysing the total resultant sound at a point into components arriving by different paths. This ability enables laboratory measurements of the sound transmission characteristics to be made for limited size panels or those which are not efficiently sealed into openings. The results show reasonable agreement with values predicted by theory or those measured by other techniques. Within the laboratory and in studio measurements it proves possible to separate and in some cases identify weak points in structures which provide low insulation flanking paths for acoustic signals.

It is possible to measure the absorption coefficient of materials in situ but only in a restricted frequency range.

7. REFERENCES

1. Goff, K.W., 'Analog Electronic Correlator for Acoustic Measurements', Journal of the Acoustical Society of America 27, March 1955, pages 223-236.

2. Goff, K.W., 'Application of Correlation Techniques to some Acoustic Measurements', Journal of the Acoustical Society of America 27, March 1955, pages 236-246.

3. Raes, A.C., 'Tentative method for the measurement of sound transmission losses in unfinished buildings', Journal of the Acoustical Society of America 27, January 1955, pages 98-102.

4. BBC Research Department Report No. B-066, Serial No. 1958/8.

5. Cremer, L., 'Die wissenschaftlichen Grundlagen der Raumakustik', Band III Wellentheoretische Raumakustik, S. Hirzel Verlag Leipzig 1950, page 173.

8. APPENDIX: THE COMPONENT PARTS OF THE CORRELATOR

8.1. Time Delays

The time delays required correspond to the time for the propagation of an acoustic signal over the distances normally found in architectural acoustics, and delays up to 100 ms have proved adequate for most measurements. It is not possible to reduce the delay below the minimum value which is obtained when recording and replay heads are touching; this amounts to 60 - 70 milliseconds at the tape speeds used in the present equipment. Since very short or zero time delays are frequently required, it is necessary to provide two complete recording channels with a variable delay in one channel and a fixed delay in the other. The relative delay between the two channels may then be varied through zero delay up to the maximum value required.

The correlator output is very sensitive to phase variations between the input signals and requires extreme stability in the generation of the time delays. Goff has proposed a maximum excursion of the time delay from its mean value of not more than 1/10th of a period of the highest frequency component common to both inputs of the correlator. For a time delay of 100 ms and a 10 kc/s upper frequency limit, the fluctuation must be less than 0·01%. In order to achieve these values, Goff utilized a rotating drum coated with magnetic material as his storage medium. The large mass involved assisted in the elimination of wow and flutter components and the use of a drum ensured that all points on the surface moved at the same speed.

However, the mechanical requirements in the construction of such a system were very stringent. Recording, replay and erase heads were maintained out of contact with the surface of the drum to eliminate wear; this necessitated a clearance between the surface of the drum and the heads which varied by less than ± 0·0001 in ($2{\cdot}5 \times 10^{-3}$ mm) to maintain the high frequency response.

In view of the difficulties involved in the construction of such a delay unit, it was decided to modify an experimental tape recording system. The first model recorded the signals on a loop of tape but it proved impossible to prepare a loop in which the joint did not cause a variation of speed every time it passed a head, guide or similar obstacle. It was therefore decided to use reels of tape and to simplify the layout to reduce the numbers of guides. Fig. 10 shows the drive system which is employed. It permits the isolation of the working length of tape from variations of torque arising both in the take up and in the feed spools. The tape is driven by a capstan at two points and passes over a pulley between these two points. The two sets of recording heads are mounted on the two sides of the loop so formed.

In order to eliminate variations of tape speed due to inaccuracy in the construction or mounting of the idlers, the system would normally be arranged so that the tape contacts the capstan rather than the idler before the driving point is reached. The standards of accuracy required in the construction of the pulleys involved in the loop should be comparable with those of the capstan.

The low frequency components of the speed fluctuation are principally due to the motor-capstan assembly and have a fundamental frequency corresponding to the rotational speed of the motor. This could be reduced below the present value of 0·05% R.M.S. with improved types of motor which are capable of 0·01%.

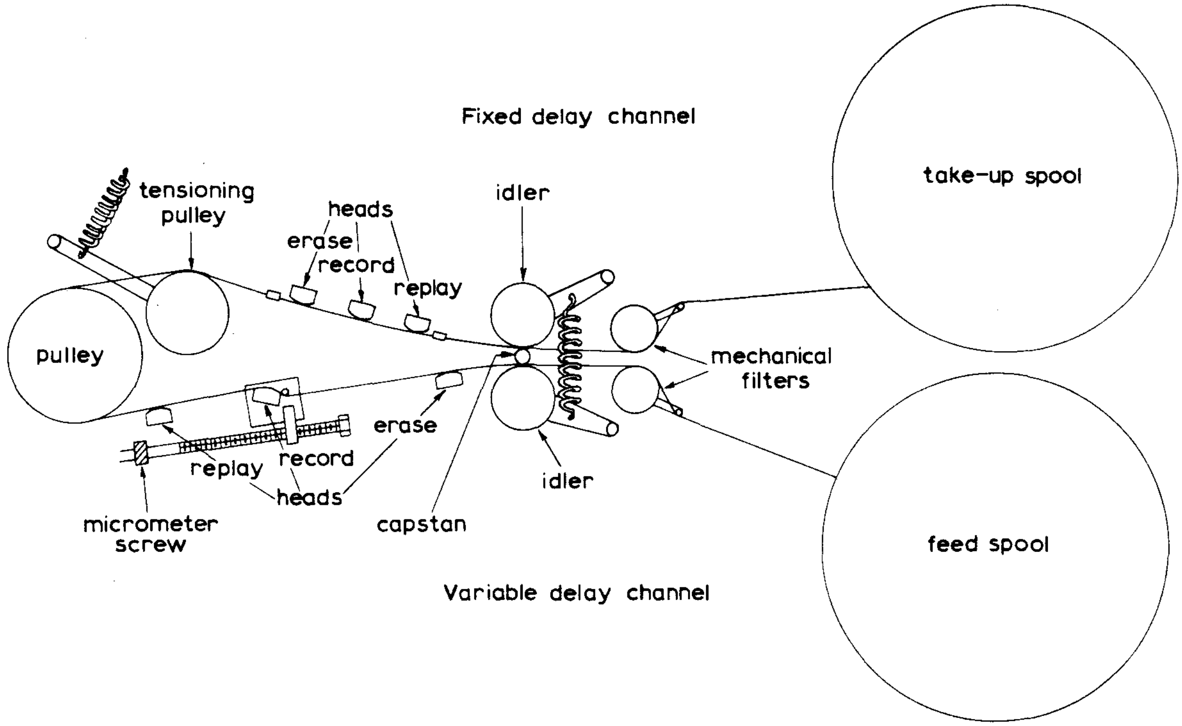

Fig. 10 - Magnetic recording tape delay unit

The high frequency components of speed fluctuation are principally developed by friction between the recording tape and stationary points on the system. In order to reduce this flutter to the minimum possible, the heads and guides are cleaned regularly. There exists only one fixed guide around which the tape is pulled, the remaining guides merely setting the height of the tapes. If there are significant variations in the width of the recording tape these guides, which must be manufactured to a close tolerance, can still give rise to variable friction.

Additional mechanical filters are incorporated outside the loop to reduce further the variations of torque arising in the motor driving the take up spool and the brakes limiting the speed of the feed spool. They are of the conventional type having a spring loaded arm and a flywheel with the tape wrapped around it sufficiently to avoid slip. The resonance frequency of the filter is of the order of 4 - 5 c/s and is below most disturbing frequencies. Sufficient damping is provided to prevent oscillation if the system is excited by a transient.

It is not possible to specify a figure of wow and flutter which would be necessary on a loop configuration such as that described here to reduce sufficiently phase variations at the input to the correlator. The measured values are of the order of 0·06% R.M.S. but vary according to which channel is measured, the time for which the system has run, the length of the variable delay and the relative amount of tape on feed and take up spool. A more meaningful measurement is a direct comparison of the phase at the two replay amplifiers, and this is found to be approximately one tenth of a cycle at 4 kc/s. These factors limit the equipment described

here to use at frequencies below 4 kc/s although qualitative results may be obtained at higher frequencies.

8.2. The Multiplier

In the equipment at present in use the multiplier is of the same form as that described by Goff and known as a quarter-squaring multiplier. A type of valve was chosen which could be arranged to give an output proportional to the square of the input. Great care must be taken in the selection of the valves, but even so this form of multiplier is sensitive to changes of mains voltage and to temperature variations.

An attempt has been made within Acoustics Section to utilize a multiplier based on the Hall effect by which a voltage is developed across the breadth of the conductor when a current flows along its length and a magnetic field exists at right angles to both these directions. Indium arsenide, a semi-conductor, has proved suitable for this application having a small temperature coefficient for the Hall effect and low resistance plates giving a high output for a given dissipation. However, Hall effect multipliers themselves tend to drift due to heating when the maximum drive current is passed into the plate. No experience has yet been gained in the use of the new multiplier.

8.3. Integrator and Indicating Device

Since the definition of the correlation function requires the limiting value of the integral as the integrating time tends to infinity, an approximation only can be obtained in a finite time. A low pass RC filter performs the integration and this requires a time of 3 RC seconds to come within 5% (½ dB) of an abrupt change in the correlation function. Four integrating times are available and may be selected to provide the optimum response under given working conditions.

The D.C. output of the integrator modulates linearly a 1 kc/s square wave, the carrier being suppressed. This signal is amplified and drives a high speed level recorder. In order to maintain a simple relationship between the results plotted by the level recorder and the delay time (or path length with which it is directly related) the level recorder is arranged to drive at a suitable speed through its gear box the movable head of the variable delay channel; movement of this head is controlled by a micrometer screw thread.

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